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GROUND RANGE AND BEARING ERROR DETERMINATION AND DISPLAY FOR AN OTH RADAR SYSTEM WITH AN ARCTIC TROUGH IONOSPHERE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the algorithms used to determine range and bearing errors which might be incurred in an OTH radar system where the propagating medium includes an arctic trough. Several types of plots for displaying this error information are described along with an example.

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Foreword

This report is the second part of a two-part final report for Contract F19628-76-C-0296. Part I, dealing with the analysis of scintillation data, is entitled: "Spectral Analysis of Scintillation Data taken from an Aircraft".

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Preface

In a previous report by Langworthy (1977), 3-dimensional ray tracing techniques were used to look at range/bearing errors which might be incurred in a OTH radar system when the "actual" propagating medium (the ionosphere) has different characteristics than an assumed one. In particular, this report considered the errors incurred when an ionospheric trough, such as the mid-latitude F-layer trough (also called Arctic trough), appeared in an assumed (standard) ionosphere which did not have such a trough. The results of this study are essentially summarized in figures 15 and 16 of Langworthy (1977). There, range error and azimuth error (actually azimuthal deviation) are plotted as rough contours in a coordinate frame of elevation angle, e, and azimuth, a, where e and a refer to the initial elevation and azimuthal angle of a ray.

In this part of the final report for the contract, we summarize work which considerably enhances that reported on in Langworthy (1977). This enhancement consists basically of the following:

1) Both the "assumed" ionosphere and the "actual" ionosphere include an arctic trough but with different characteristics. Trough features such as location, width and F2-layer plasma frequency maximum on either side of the trough can differ in the two models.
2) The range and bearing error contours are shown in a more usable form on a group-path-length (or delay), azimuth coordinate system. This coordinate system is considered to be an "observational" system in that both of these quantities are assumed to be measurables.
3) The procedure for obtaining the error display is for the most part automatic. Thus, the user merely inputs a description of the target zone in terms of two range and two bearing limits. (Height limits can also be given but they are not used. The target zone is considered to be on the ground.)

In addition to providing the above enhancements, a routine was developed which graphically displays the "astigmatism" which the propagation medium introduces. This astigmatism is shown by producing a (distorted) coordinate system of constant group path length (g-p-l) and constant azimuth superimposed on a (non-distorted) target grid of range and bearing.

The following remarks are indicative of areas for further study of work completed under this contract and summarized in this report.

1) A study of the focusing and defocusing effects of an irregular ionosphere such as that used in this study was not continued. This was reported on in Langworthy (1977) as contours of power loss differences (actually gain or loss of signal strength of the trough ionosphere over the non-trough one).
2) Because of lack of time, only a few pairs of "actual" and "standard" ionospheres were run through the system. In this report we include figures for only one such pair. There are several parameters which can be varied, namely trough location (this can be considered to be a multiparameter variable since the trough edge is defined by a set of geographical coordinates), trough width, the plasma frequency maximum of the F2 layer at the "shoulder" of the trough and the same for the bottom of the trough. Finally, for any pair of ionospheres, frequency can be considered as another parameter.
3) Although we feel the "devices" (sets of software modules) for producing the error displays are adequate, some "fine tuning" of them is required. Thus, the procedure which attempts to cover the target area with an adequate set of rays iterates only once. In some instances there should probably be more than one iteration.

* Langworthy, B.M. (1977) "Some Examples of the Effects of the Poleward F-layer Trough Wall on Ground Range and Azimuth Determination in an OTH Backscatter System", AFGL-TR-77-0075, Parke Mathematical Laboratories, Carlisle, Mass.

Introduction

The body of this report consists of two sections. The first section is a general description of the various figures which are produced by software developed under this contract along with their significance. The second section goes, in considerable detail, into the algorithms used in this software along with a discussion of various parameters available to the user for controlling what is produced. The appendix includes some job examples and copies of the various Procedures which are used. Further details on the software referred to may be found in the various internal reports by Parke Mathematical Laboratories, Inc. (usually) and as a last resort in comment lines which are part of all of the software. These write- ups are available at PML but are too numerous to include as part of the report.

Section I

Basically, two types of displays are the end result of applying the software developed to investigate possible OTH errors. In this section a brief explanation is given on how the displays are produced and how they can be interpreted. Other sections provide the technical details for the production of the displays.

The first display to be described is the "distorted grid" display which graphically depicts the "astigmatism" introduced by a propagating medium with irregular features. Figure 1. is an example of such a display for a typical arctic trough configuration, i.e., the propagating medium is the ionosphere described in Langworthy (1977). It is basically a two-layer ionosphere with a Chapman E-layer up to the E layer maximum at 120 km followed by a sine-squared F2-layer with a maximum at 350 km. The ionosphere is constant on either side of a boundary called the poleward trough wall (but has different foE and foF2, i.e., different plasma frequencies at the E and F2 layer maxima, respectively) in the two regions defined by this boundary. In the trough-wall itself, foE and foF2 vary linearly across a defined width. The two values for foE are fixed at .1 MHz (south of boundary) and 2.5 MHz (north of boundary) while similar values for foF2 are input parameters. The trough wall depth is also an input parameter.

See Figure 0 for the location of the trough wall and the ionospheric parameters for the two models, TROUGH1 and TROUGH1A, used in preparing this report.

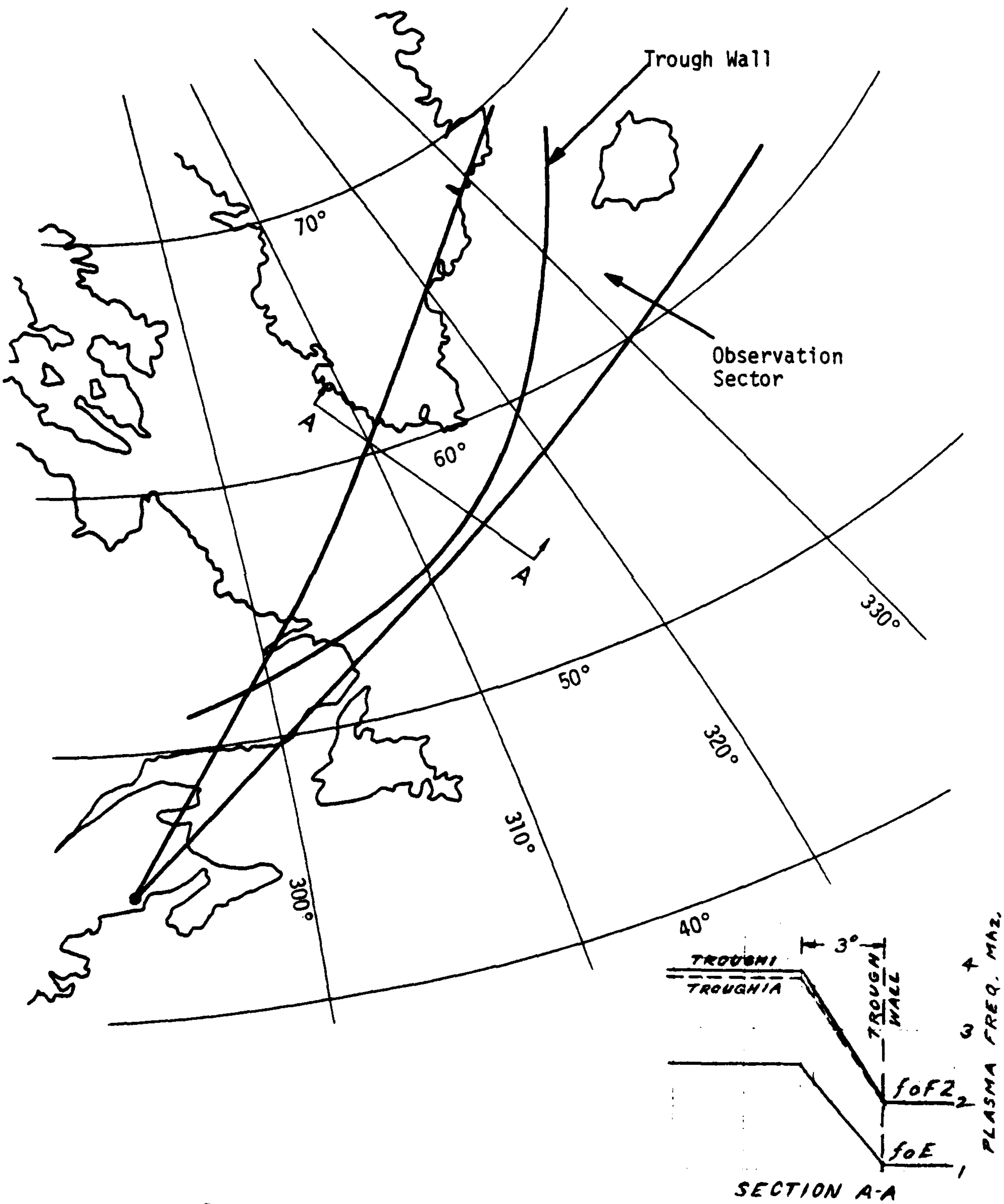


FIGURE O. GEOGRAPHIC LOCATION OF THE TROUGH WALL AT 06 UT

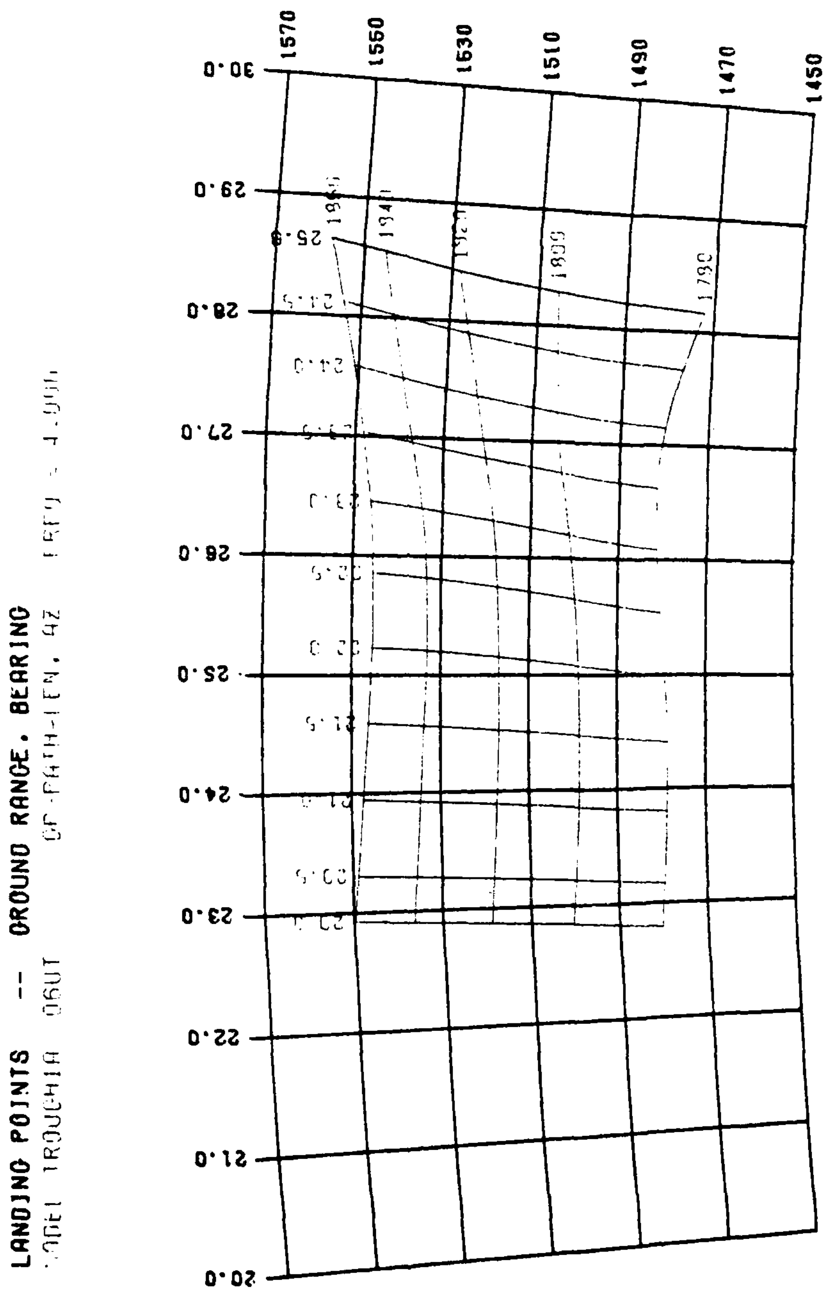


Figure 1. - Distorted Grid Display

This figure "shows" the transformation between two coordinate systems: the transmitter centered spherical coordinate system (shown here as ground range and bearing segments) and the "observational" system of azimuth and group path length. Specifically, azimuth is the initial azimuth of a "ray" from the transmitter, (or, assuming reciprocity, the arrival angle of a ray from a target) and group path length, GPL, is one-half the measured delay time of a pulse striking a target times the speed of light.

As an aside, it might be noted that if a single "reference" target with known bearing and range is available within the target area (here the target area is considered to be the transmitter centered spherical system), it is possible to "normalize" the observation grid system. For example, if the observed azimuth of 25° and GPL of 1790 km corresponded to a known bearing of 28.75° and range of 1490 km, respectively, it would be possible to label the 1790 km coordinate line as 1490 and the 25° coordinate line at 28.75°. The other coordinate lines would then be similarly relabeled.

The significance of this figure is not so much that it depicts the transformation between a measurable coordinate system and a desired coordinate system but that it is indicative of the complexity of this transformation. Thus, we use the term "astigmatism" in a loose sense to show how a regular pattern (the transmitter centered, spherical system) is distorted when looked at through an ionosphere with an irregular feature like the mid-latitude trough. In order to produce this figure, we knew what the ionosphere was. In reality, the ionosphere is not known. It may be possible to fix one or two points on the "measured" grid system (say by the use of known targets) but the distortion of the grid (no matter how you measure it) is indicative of the uncertainty of an algorithm which might be devised to effect the transformation from one system to the other.

Figure 2. is more to the point of this report. It is the same as Figure 1. except another "observed" coordinate system has been added.

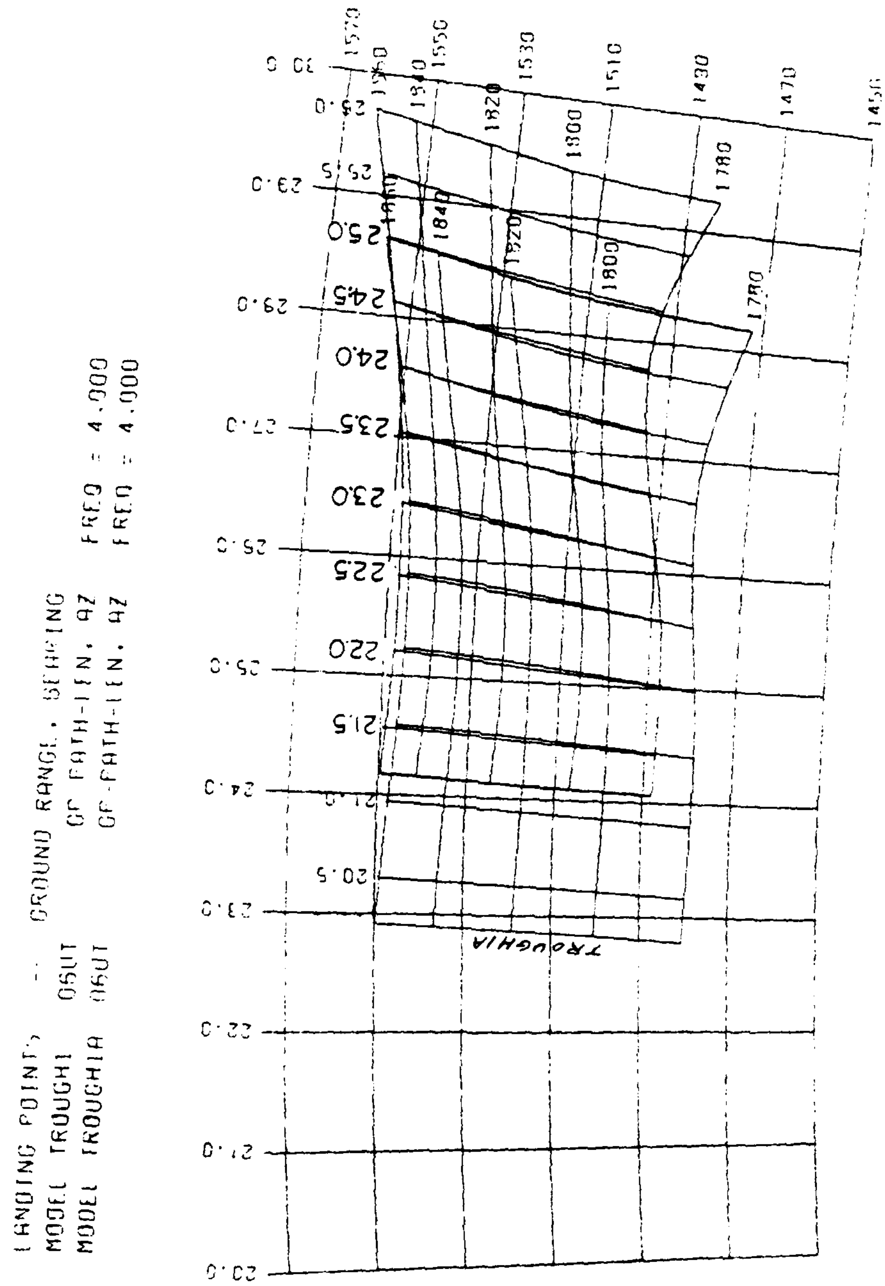


Figure 2. - Distorted Grid Display - 2 Models.

The figure illustrates quite dramatically the range/bearing errors which might be incurred in assuming one ionosphere when, in fact, another one existed. (The second ionosphere has the same wall geometry as the first; only the value of foF2 has been changed. For this reason, bearing differences are quite small.) Thus, it is assumed that a transformation algorithm from the observed-desired is available on the assumption that ionosphere TROUGH1 exists. Actually, however, TROUGH1A exists and one can read off of the figure directly the range and bearing errors which exist in various regions of the target area.

Note, however, that the range/bearing errors read from the figure might be quite pessismistic if the "system" is capable of continuous recalibration. Thus, if a single known target is available within the target area, it is possible to align the two grids on this point. Or more exactly, a target offset (direction and magnitude) can be computed. If this is done, the residual difference in the two grids is the true measure of the error introduced by the "actual" ionosphere.

Figure 3. shows directly the error involved in the transformation when one ionosphere is assumed as "standard" (the one on which the coordinate transformation is based) and another ionosphere actually exists. The errors (one for bearing and one for range) are shown as contours of constant error (either range in km or bearing in degrees) on a GPL, azimuth coordinate frame where GPL and azimuth are those for the assumed standard. In producing these contours, no attempt is made to minimize any "systematic" error which might be eliminated from a priori target knowledge as mentioned above.

Figure 4 is a perspective view of these error surfaces -- useful for perceiving the errors but not obtaining numerical values.

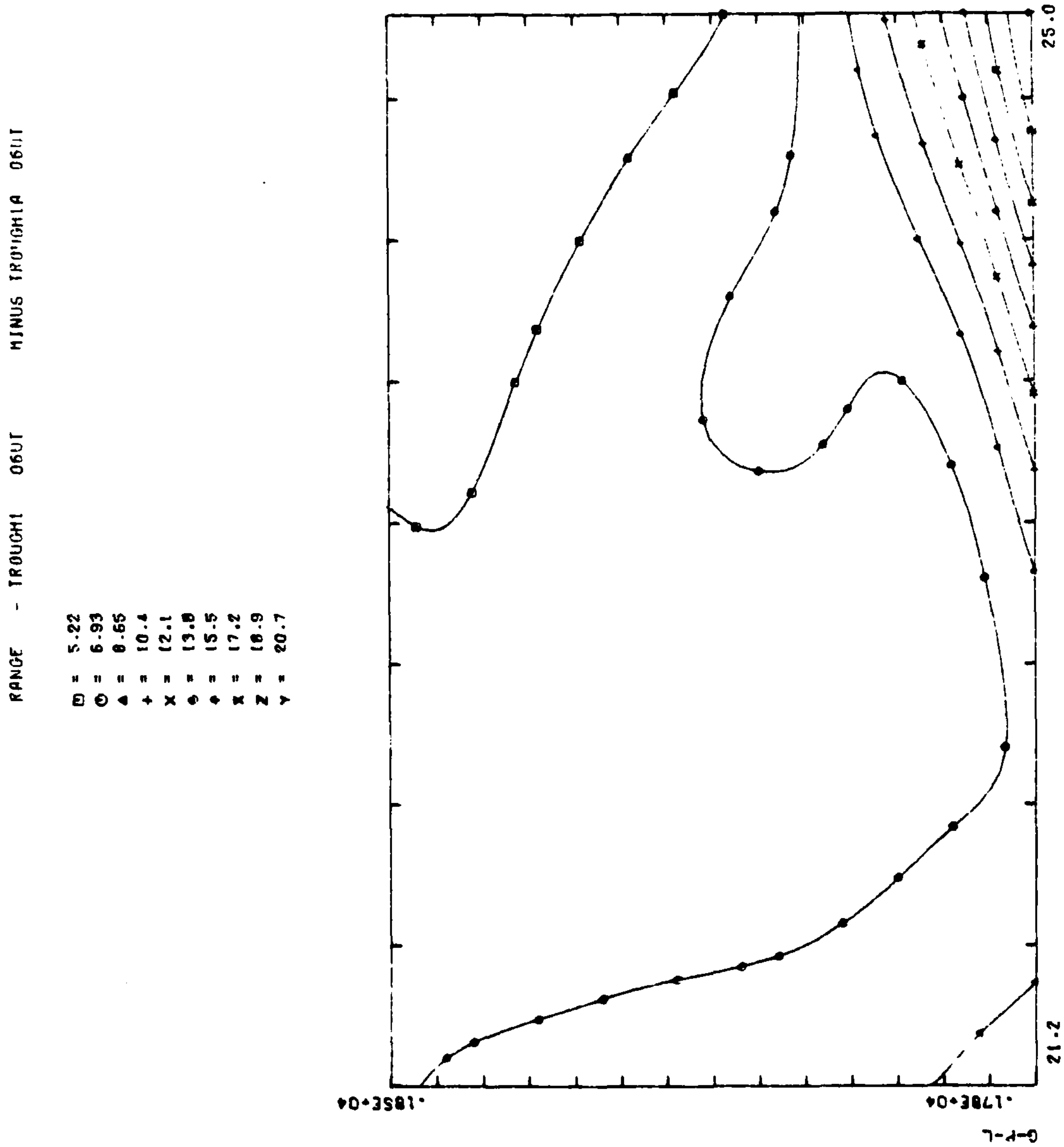


Figure 3a. - Contours of Range Error in Km

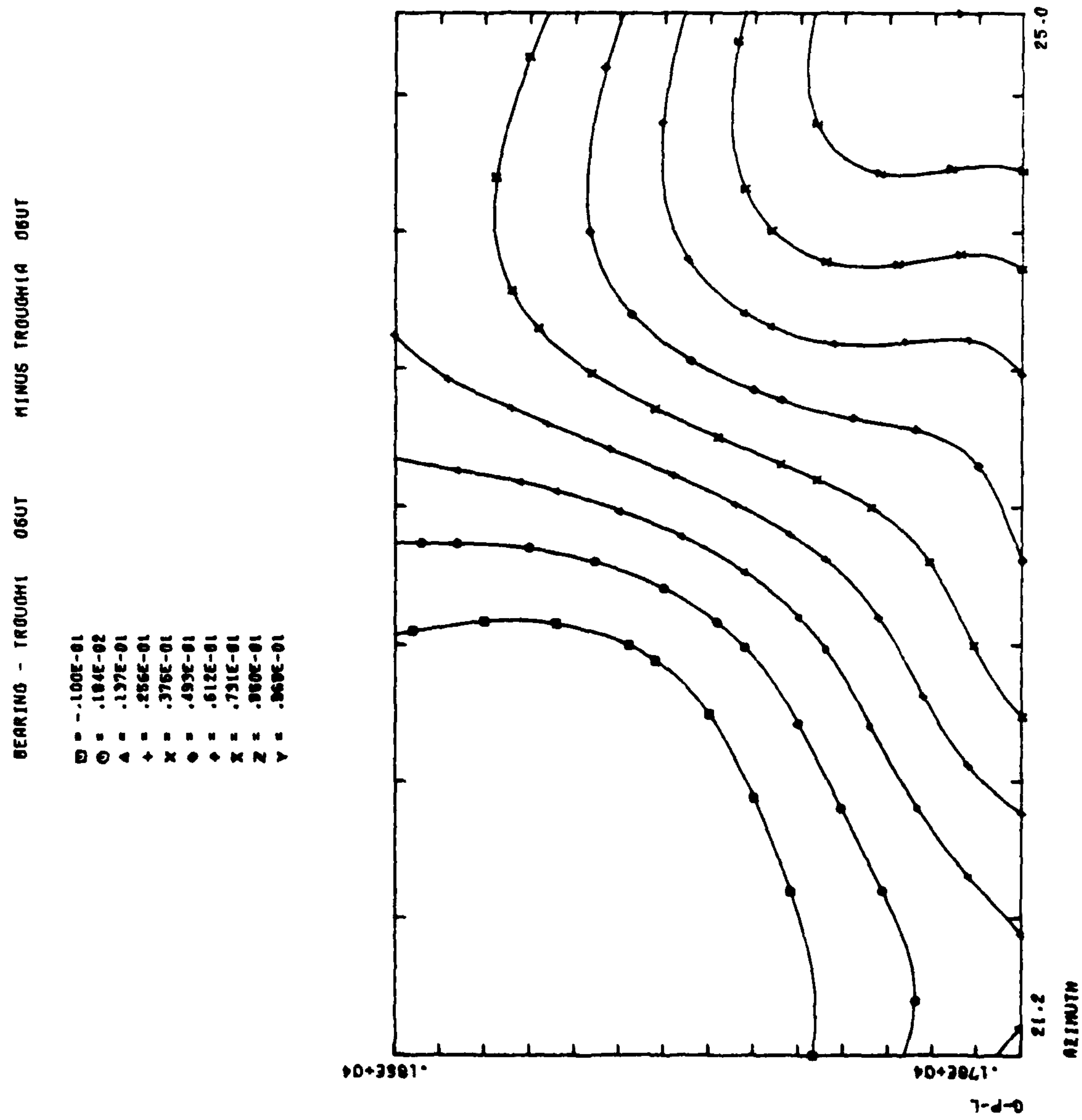


Figure 3b. - Contours of Bearing Error in Degrees

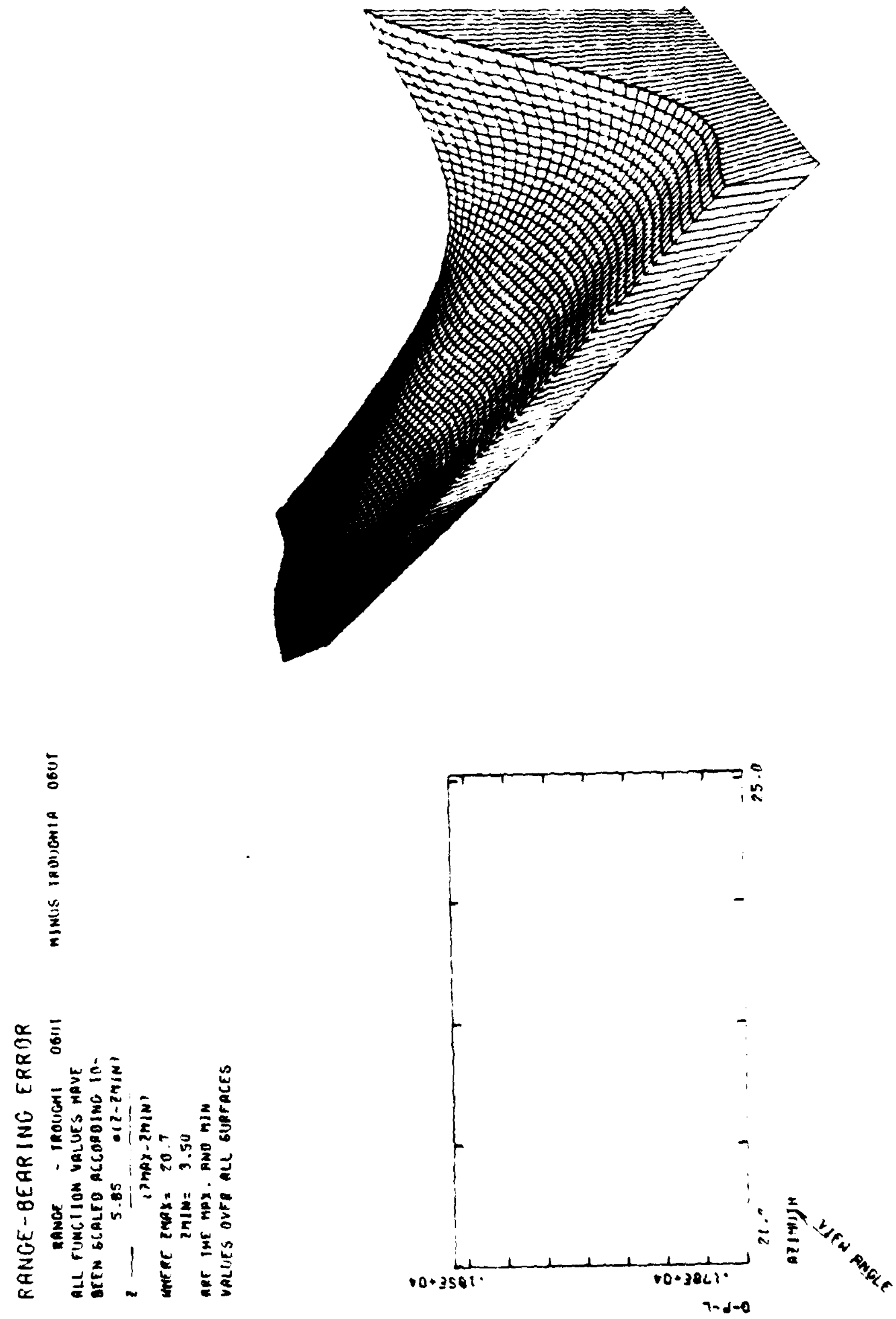


Figure 4a. - Perspective View of Range Error

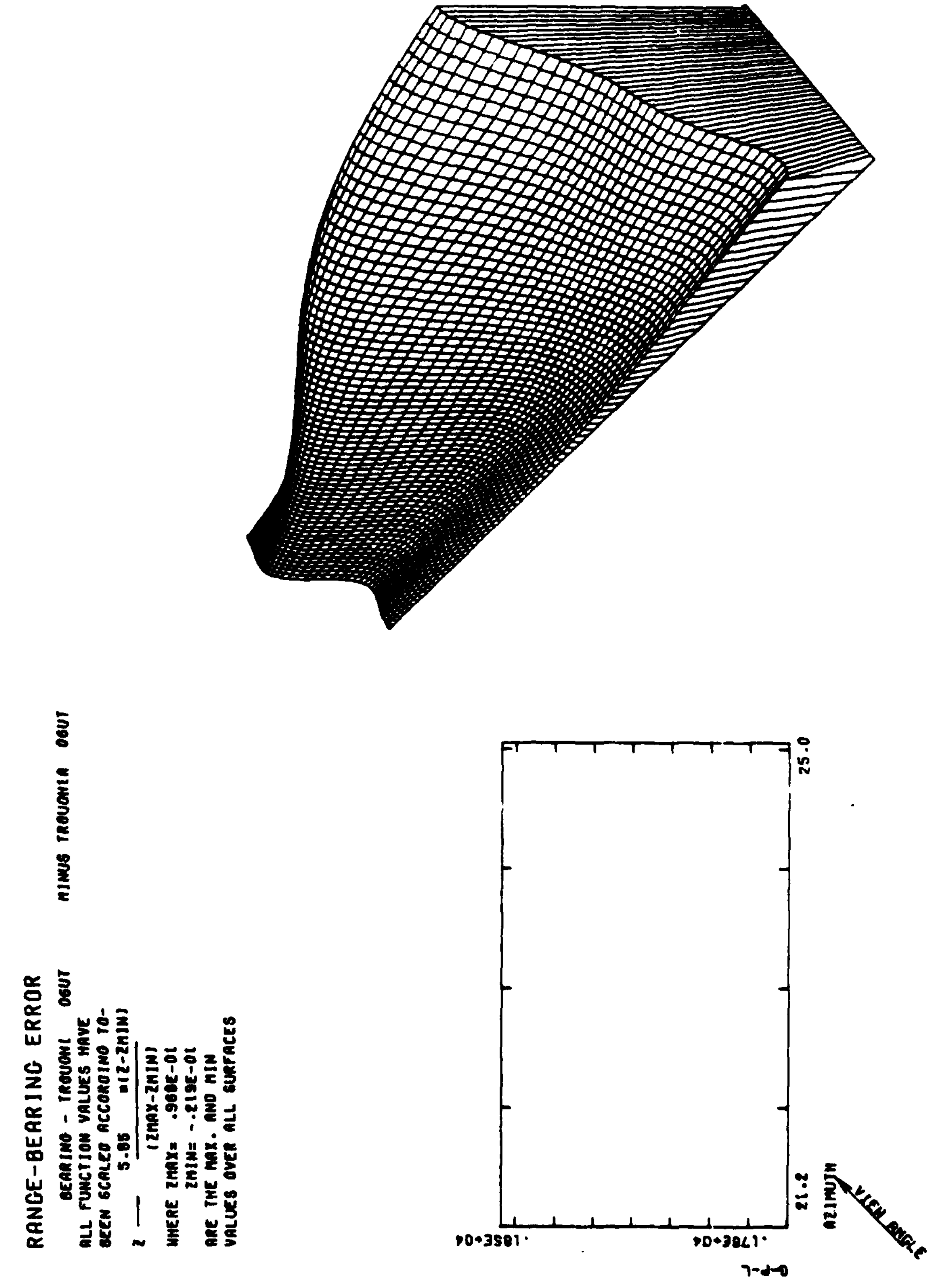


Figure 4b. - Perspective View of Bearing Error

Section II - Technical Details of the Displays

In this section, some of the technical details of generating the displays of the preceding section are presented. It has been found convenient to break down the overall task into 3 hierarchies. At the highest level is a set of Procedures which the various "devices" together with the operating system and possibly the user use to perform a given sub task. At the next level are the "devices" which actually consist of one or more software modules which collectively perform a sub task. At the lowest level are the individual software modules (subroutines). It should be noted that both Procedures and "devices" can invoke other (sub) Procedures or sub "devices".

In order to explain what goes into producing the 4 figures in a lucid manner, we give and explain two diagrams, each of which are "flow diagrams" but showing different sorts of information.

The first diagram, Figure 5, is a descriptive diagram showing task flow from Procedure to Procedure and within a Procedure from device to device. In addition, a brief description of what each device does is given. The dashed rectangles indicate Procedures while solid ones indicate devices. The slanting dashed arrows between Procedure boundaries, or between Procedure and device, indicate user supplied (or by default) data flow. The numbers 1 and 2 on the two output branches of MKTAP8 indicate that on the first time through, the output of MKTAP8 is used to produce another input (W-array) for JBRAYS, while on the second time through, the output goes to MKTAP9. Later, the task descriptions shown on this diagram are expanded below.

The second flow diagram, Figure 6, is mainly to show data flow from device to device. For clarity, Procedure boundaries have been omitted. This diagram can also serve as a "user" diagram in that it lists all the important user supplied data (on the right, by Procedure name). These data are given by the user as Procedure parameters only if required to override the default values shown in parantheses. Most of the data terminology is fairly self- explanatory but we elaborate on it below. (For simplicity, some of the Procedure parameters have been omitted since they are usually not used. A complete list of Procedure parameters is given elsewhere.)

Procedure/Device Flow Diagram

STEP 1 -- Produce the display data for one ionosphere
(This step is repeated for figures 2, 3, 4.)

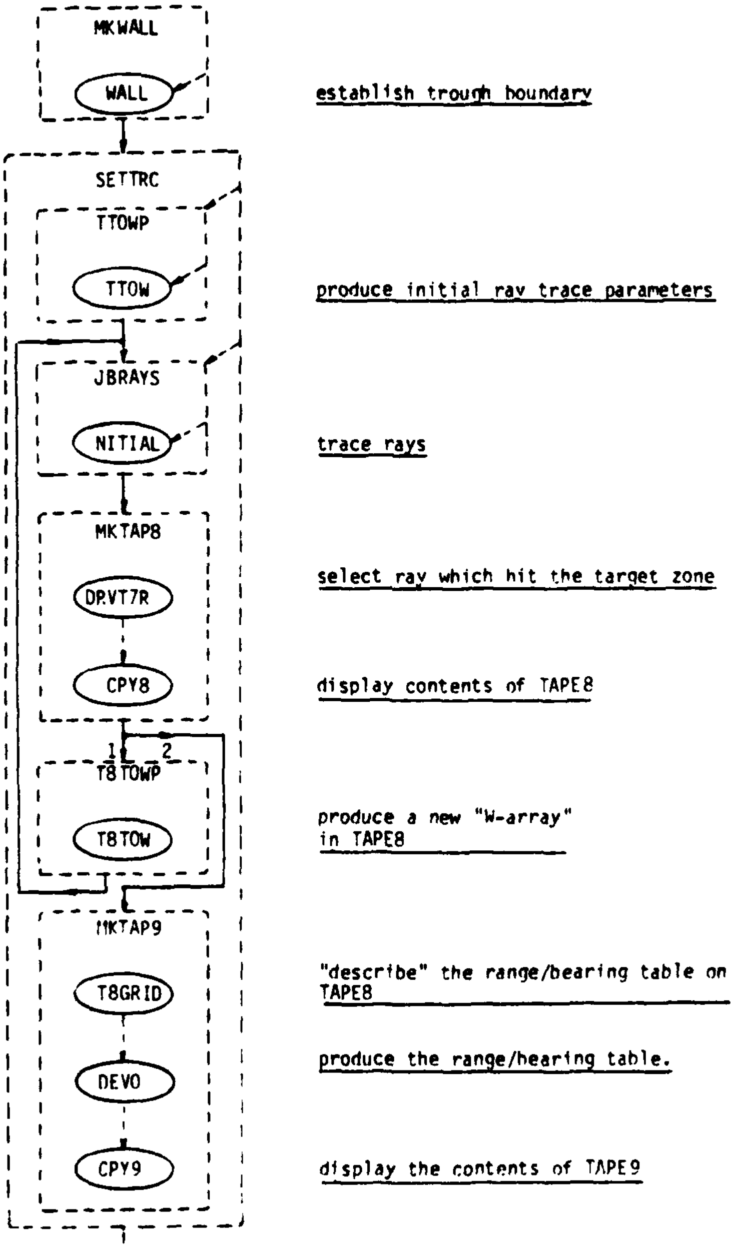


Figure 5a. - Procedure/Device Flow Diagram

STEP 2 -- Produce figures 1, 2, 3,4

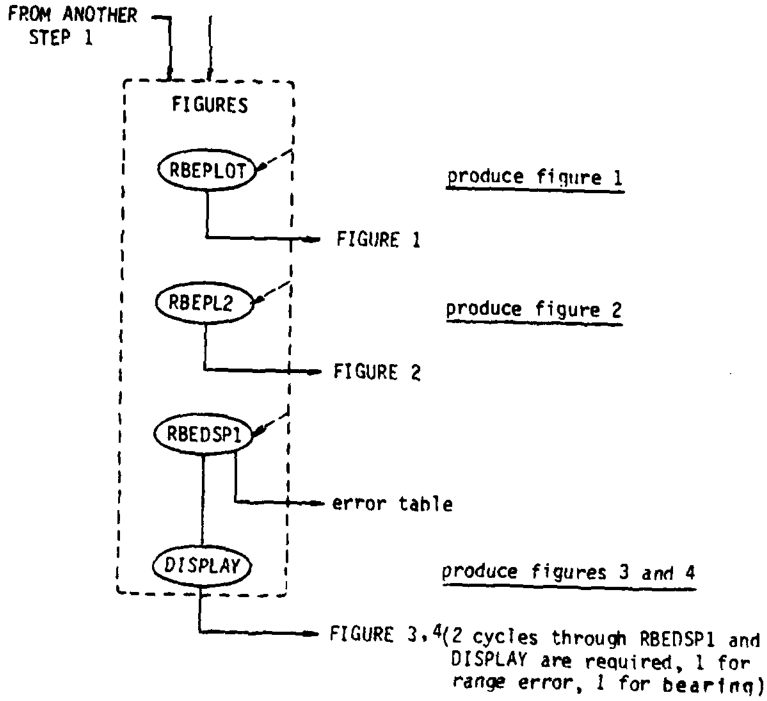
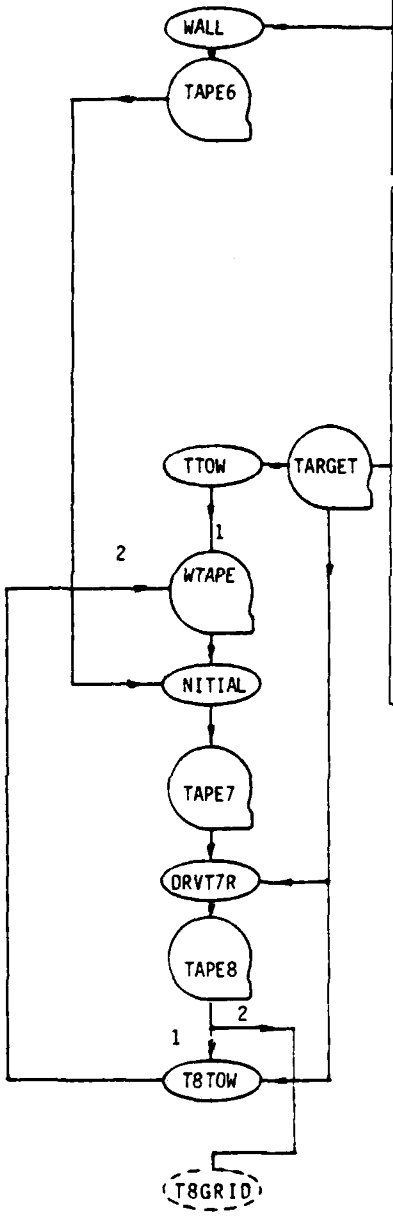


Figure 5b. - Procedure/Device Flow Diagram (Continued)

Data Flow Diagram



MKWALL
Specify trough boundary by geographic latitude for geographic longitudes [295.,340.(5.)].
L295(51.5),L300(52.5),L305(53.7),
L210(55.4),L315(57.2),L320(59.6),
L325(61.9),L330(64.3),L335(66.3),
L340(68.2),MODOU(O6UT)* 1-word title to identify trough boundary.

SETTRC

(1) target zone description
- AZL(24.0),AZH(37.0) low/high azimuth limits (deg dipole geomagnetic)
- HTL(0.0),HTH(10.0) low/high height limits (km)
- RNGL(900.0),RNGH(1150.0) low/high range limits (km)

(2) trough parameters
- F2MX(3.81) max plasma frequency (MHz) at "top" of trough
- F2MN(1.97) max plasma frequency (MHz) at "bottom" of trough
- PMAX(3.0) trough width (if PMAX$\leq$ .2, width is in radians; otherwise, degrees)

(3) describe rays (initial description)
- FRL(4.0) low frequency limit (MHz)
- FRH(9.0) high frequency limit
- FRSTEP(1.0) frequency step
- ELL(0.0) low elev. angle limit (deg)
- ELH(30.0) high elev. angle limit
- ELSTEP(4.0) elevation step

(4) MODOU (TROUGH1)

* default data values are shown in parentheses.

Figure 6a. - Data Flow Diagram

Data Flow Diagram (continued)

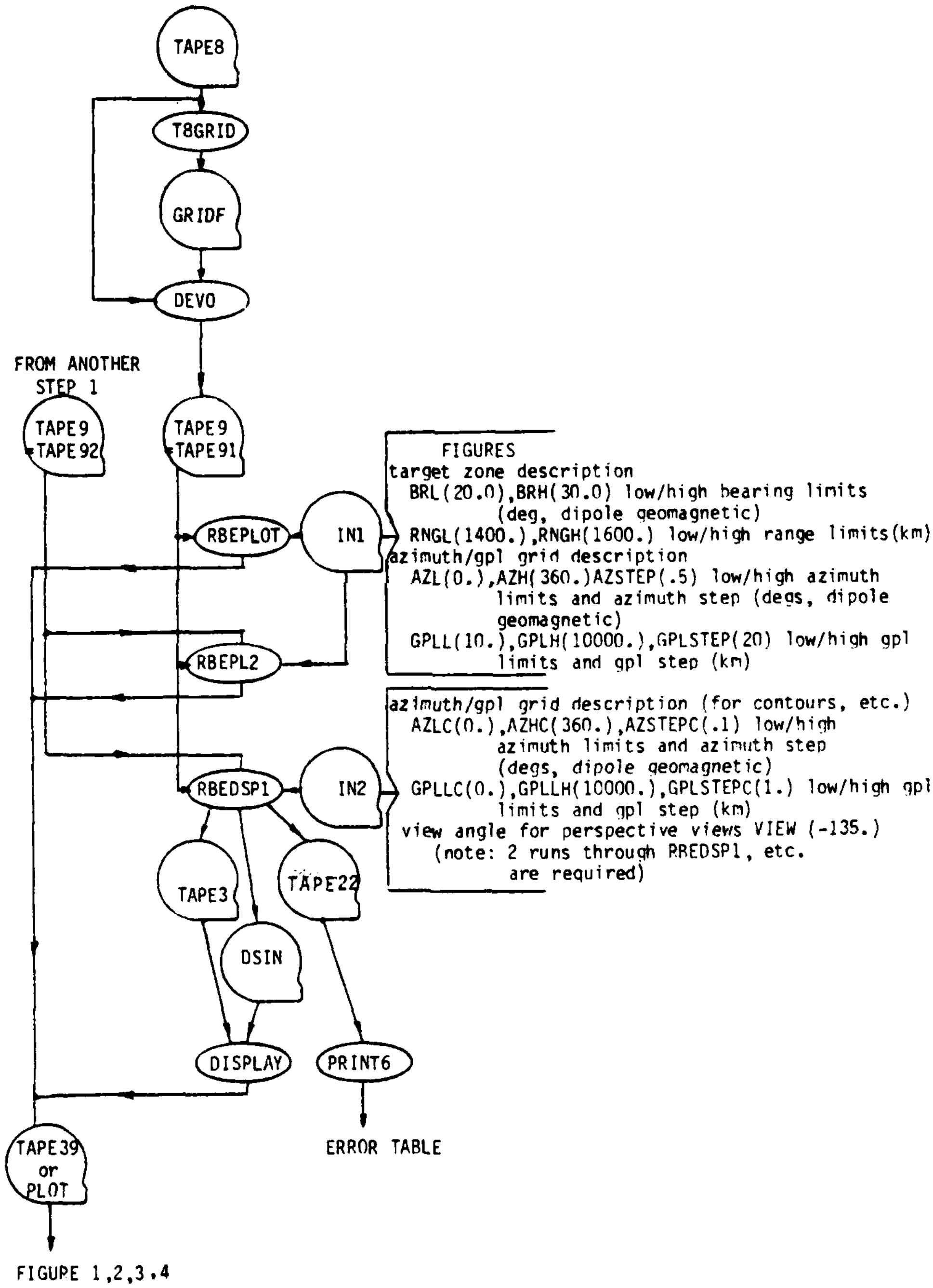


Figure 6b. - Data Flow Diagram (Continued)

MKWALL - The trough boundary should be identified in some fashion. Note that the "reference" and "actual" ionospheres may have different trough boundaries with all other parameters remaining the same. *In the example shown in Section I, the boundary remains constant* and the trough parameter F2MX is varied.

The longitudes of the boundary are fixed at the values 295., 300., ..., 340 so the user can only specify corresponding geographic latitudes, e.g. L295=51.5 means that the trough boundary goes through a point with latitude 51.5° and longitude 295°. (Note that all latitude values must include the decimal point which means, in turn, that they must be enclosed in $$.)

SETTRC - This Procedure calls many other Procedures and passes parameters to them. The target zone for which range/bearing errors are to be found is a solid (usually) on the earth's surface bounded on the bottom by a sphere of radius R+HTL (R=radius of the earth), on the top by a sphere of radius R+HTH, by two sections of cylinders perpendicular to the earth's surface, and through the two range circles with center at the transmitter and radii corresponding to the ground ranges RNGL and RNGH. The other two sides of the target zone are formed by vertical planes through the bearing lines AZL and AZH. It should be noted once and for all that the target zone azimuths are true bearings and preferably are referred to as such to prevent confusion with the use of azimuth when describing the coordinate system "defined by" the propagating medium. Here azimuth refers to the azimuthal direction of wave propagation at the receiver. As a rule, because of lateral deviation of rays, azimuth (for waves) is not equal to bearing. In particular, as shown in the preceding section, the difference can be quite substantial. Note that bearings or azimuths are relative to dipolar- geomagnetic north. (Positive azimuths are clockwise.) For a transmitter/receiver at 44.8°N, 67.8°W (geographic) and geomagnetic pole at 78.565°N, 89.761°W the bearing relative to geographic north is about .7° less, i.e., if the geographic bearing is 25°, the geomagnetic bearing is 25.7°.

The target zone usually extends from the earth's surface to perhaps 10 km above the surface (HTL=0, HTH=10). The actual thickness (=HTH-HTL) used is not particularly critical but should probably be non-zero, i.e., always HTH>HTL.

The trough parameters (not including the trough boundary given above) are the two F2-layer maximum plasma frequencies on either side of the wall and the thickness of the wall. Note, in particular, that wall thickness can be expressed either in radians (values $\leq$ 2 are assumed to be radians) or in degrees. F2M2 refers to the plasma frequency at the trough boundary (as specified to MKWALL) while F2MX is the plasma frequency on the northern side of the wall. (In general, the trough, or wall, goes geomagnetically east-west so it makes sense to talk about the northern and southern sides of the wall.) More details about the ionospheric modes can be found in the appendices to Langworthy (1977).

The user must specify what rays are to be traced initially. There are two main considerations in specifying this "starting" data: the time involved in tracing rays and the likelihood of covering the target with a portion of the rays. It takes roughly 1 second to trace 1 ray for 1 hop propagation using this particular ionospheric model. The user can choose a frequency range with FRL, FRH, FRSTEP for low frequency, high frequency and frequency step. Later in the sequence of tasks (see below) which process the output of the initial ray trace, an "optimum" frequency is chosen. At this frequency, the target is most optimally covered by rays. Initially the user will probably trace rays at several frequencies just to get an idea of what elevation angles and azimuths are suitable for different frequencies. The error displays should be for the same transmitter frequency so the second "TAPE9" should be for rays traced at a frequency equal to that for the first TAPE9. This means that FRL=FRH.

An alternative to using ray tracing to find target coverage (at least for elevation angle estimates) is to use the analytical form for a quasi-parabolic layer which approximately matches the sine-squared layer actually used. The fact that there are actually 2 layers complicates the problem, however. Moreover, the situation becomes quite complex for rays which are in the ionosphere near the trough wall.

Initial estimates of azimuthal angles are not an option left to the user. Rather the following algorithm is used to calculate initial azimuths to use:

```
AZSTEP = (AZH-AZL)/3
AZSTART = AZL-MIN(6.,AZSTEP)
AZEND = AZH
```

where AZL and AZH are the target zone bearing boundaries specified above.

It should be noted that, at present, single hop propagation is assumed.

FIGURES - The user is allowed some control over the display as described below.

The target zone grid system is specified by the low and high bearing limits, BRL and BRH, respectively, and the low and high range limits RNGL and RNGH. This target area displayed does not have to conform to the target zone chosen above but it is usually convenient to make them the same. The user has no control over the grid interval -- this is chosen by a subroutine for "good" values.

The amount of the "distorted" grid to be displayed is specified by the parameters AZL, AZH, AZSTEP for low, high azimuth and azimuth step, and by GPLL, GPLH, GPLSTEP for low, high group path length, and group path length step. The outer grid limits are actually determined by the values in the table produced by DEVO. (See, for example, the contents of the output, GRIDF, from T8GRID.) At this point the user can only restrict the distorted grid limits by choosing values such that they will cause only part of the grid to be drawn. To get the whole grid, choose the default values which will, of course, be overridden by the actual table limits. The steps in azimuth and GPL, AZSTEP and GPLSTEP determine the spacing of the grid lines. For example, if AZSTEP=.5, an azimuth grid curve will be drawn every .5^{o}. These step values are also used to determine the step size for drawing the grid curves. At present a point is computed at half-step intervals. (This is subject to change but is not a user option.)

The parameters for the error contours are used in much the same way as the "distorted grid" parameters. Here, of course, there is no target zone grid to be drawn so only azimuth and GPL limits can be specified. Again, the outer limits are determined by the contents of the two "TAPE9's" which contain the range/bearing tables. The increments in azimuth, AZSTEPC, should be chosen such that a maximum of 100 azimuth values are used.

Returning to the Procedure/device flow diagram (Figure 1.), we give a more detailed description of the various tasks with appropriate references.

(1) establish trough boundary

The trough (southern) boundary is given by a series of great-circle arcs through the end points specified by the user. (Actually in Procedure MKWALL, only latitudes are given by the user for prescribed longitudes.) A description of the algorithm for producing the boundary and the electron density model associated with trough are given in Langworthy (1977), Appendix A and B.

(2) produce initial ray trace parameters

The initial "W-array" input for the ray trace program is produced by TTOW (PML345). [Note -- various software "devices" are described by PML write-ups which are assigned numbers. Thus, the device is referred to by name usually the name of the entry point to the device, or by PML n where n is the number asigned to the device and its write-up.] Part of the W-array is merely a translation of the data given by the user. The rest are parameters fixed by data statements in TTOW or are given by default values in the ray trace program (see below). Note that the geomagnetic pole and geographic poles are made to coincide so all locations must be geomagnetic coordinates.

(3) trace rays

For details of the ray trace program, see PML121 or TM41. The electron density subroutine is, of course, BCHAP as described in Langworthy (1977), Appendix B. The output file TAPE7 is used in the next step.

(4) select rays which hit the target zone

Device DRVT7R includes program DRVT7R and subroutine T7RRSET. T7RRSET is basically the same as CRRSET which is described in PML157 or see CRRSET1 (PML157A) for a variant. There is one important difference however. CRRSET includes provisions for selecting points on a ray according to their label. For example, a point might be labeled "ENTR ION" to indicate that this point on the ray is where the ray enters the ionosphere. T7RRSET on the other hand selects a ray if any point on the ray lands in the target zone. Usually this amounts to selecting rays which hit the earth within the target area assuming ELL is 0 which it should be. The following data about each such ray and its landing point is recorded on TAPE8, the main output of DRVT7R -

range (km), bearing (radians), r (km), GPL (km), initial azimuth (radians), frequency (MHz), hop number (always 1 at present), initial elevation (radians). (r is the radius of the landing point in the compute system. Typically, $r=R_e=$ earth radius.)

The contents of TAPE8 may be printed in a convenient format using device CPY8.

(6) produce a new "W-array"

This step is probably the most crucial one in the entire procedure since on its guess of appropriate rays to trace, rests the success of the construction of an adequate range/bearing table. The present algorithm can be explained quite simply as follows: (see T8TOW - PML347 also)

(a) If no rays hit the target, then use values which are given in the INPUT file. Since the input file in this case is TARGET, the same files as was used to create the initial W-array, this is not a good strategy.

(b) If rays have been traced at several frequencies, choose the best frequency according to the maximum value of the measure , S, where

$$S = \mathrm{sqrt}\left[\left(\frac{\text{del-az}}{B}\right)^2 + \left(\frac{\text{del-rng}}{R}\right)^2\right] ,$$

del-az = maximum azimuth spread of landing points in the target area.
del-rng = maximum range spread.
B = target area bearing spread (b_h - b_l).
R = target area range spread (rng_h-rng_l).

(c) For the optimum frequency (if there is only one, it is optimum), choose the starting ray azimuths and elevations as follows:

$$az_l = \frac{[5(b_l\text{-dev})]}{5}$$

$$az_h = b_h$$

$$\text{del-az} = \frac{[az_h - az_l]}{10}$$

$$el_l = el_{min}-1$$

$$el_h = el_{max}$$

$$\text{del-el} = \frac{[el_h - el_l]}{10}$$

where

[ ] means integer part of

az_l, az_h, del-az, el_l, el_h del-el = the starting, ending, step in azimuth and the same in elevation.

b_l b_h = the lower and upper target bearings.

dev = the maximum value of [(landing point bearing) - (initial azimuth)], i.e., the maximum lateral deviation of all rays which hit the target.

el_{min}, el_{max} = minimum and maximum values of starting elevation angles for rays which hit the target.

These criteria for choosing new initial values for rays are based partly on assumptions about the geometry of the trough wall relative to the transmitter and target zone. In particular, it is assumed that the maximum ray deviation as defined above is always positive.

(7) Repeat steps (3), (4) and (5) to obtain a more complete range/bearing table for interpolation.

(8) "describe" the range/bearing table on TAPE8

Device T8GRID attempts to find a "good" set of values for the construction of the interpolation table in the next step. This table can be imagined to have the form:

GPL \ az	az_1	az_2	az_3	az_4	az_5	az_6	.....
GPL_1	R_1^1 B_1^1	R_2^1 B_2^1	R_3^1 B_3^1	.	.	.	
GPL_2	.	.	.	.	.	.	
GPL_3	.	.	.	.	.	.	
GPL_4	.	.	.	.	.	.	
.							
.							
.							

where R^i_j, B^i_j are the range and bearing associated with the i^{th} GPL and the j^{th} azimuth.

Thus we wish to find appropriate values for az_1, az_2, ... and GPL_1, GPL_2, ... from information contained in TAPE8. Since azimuths are already almost in a "good" form (since they were chosen to be so initially), the lower and upper azimuths are chosen basically by rounding down to good decimal values the extreme values found in TAPE8 subject to the condition that they have at least 5 GPL's associated with them. The step in azimuth is again the same as the azimuth step size used in ray tracing.

GPL values are more difficult. The following algorithm is used (with at least 5 GPL's):

a) for the i^{th} azimuth, find $GPL_{min}(i)$ and $GPL_{max}(i)$

b) find
$$\begin{aligned} GPLLF &= \min\{GPL_{min}(i)\} \\ GPLHF &= \max\{GPL_{max}(i)\} \\ GPLLB &= \min\{GPL_{max}(i)\} \\ GPLHB &= \max\{GPL_{min}(i)\} \end{aligned}$$

c) set lower and upper GPL limits from

$$\begin{aligned} GPLL &= \max\{GPLLF,\ GPLLB - .05 \cdot (GPLHB-GPLLB)\} \\ GPLH &= \min\{GPLHF,\ GPLHB + .05 \cdot (GPLHB-GPLLB)\} \end{aligned}$$

d) select step sizes of 1., 2., 5., 10., 20., 50., or 100. km such that 26 or fewer steps in GPL lie between GPLL and GPLH and round GPLL and GPLH to the next lower multiple of the step size.

It should be noted here that if, for a given initial azimuth, the group path lengths do not monotonically decrease with increasing elevation angle, they are rejected. More exactly, GPL's are collected for a given azimuth only as long as they decrease with increasing elevation angle. (A better criterion might be to insist that range and GPL increase together.)

T8GRID imposes some array size limitations (at present) which the user should be aware of:

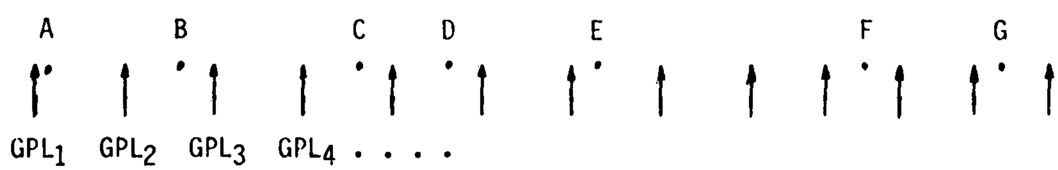
a) the maximum number of initial azimuths or elevation angles for rays hitting the target area is 50.
b) for any azimuth, the maximum number of (monotonic) GPL's is 30.

Note that these array limitations might have the effect of reducing the size of the ultimate range/bearing table. The program should not "blow-up" however.

(9) Produce the range/bearing table

Device DEVO (PML349) uses the information in file GRIDF produced in the preceding step and the contents of TAPE8 to produce the range/bearing table. For convenience, imagine the columns of the table to be labeled by the set of azimuths and the rows labeled by the set of GPL's found in the preceding step. Each entry in the table consists of the pair range, bearing (R,B). As mentioned previously, the azimuths are essentially a subset of the initial azimuths used for ray tracing so the problem boils down to one of finding the appropriate values for (R,B) for each GPL label for each column (azimuth) in the table. This is done as follows:

a) for a given azimuth (column label) read TAPE8 to get a table of triplets (GPL, range, bearing) in GPL ascending order.
b) "merge" this table with values found by linear interpolation as illustrated below:



The • indicate GPL values in TAPE8 while the vertical arrows indicate the GPL "labels" for the table.

(b1) $x(1) = GPL_1$; $y(1) = lin_e(GPL_1)$ where lin_e => linear extrapolation and y is either range or bearing

(b2) $x(2) = A$; $y(2) = \begin{matrix} R(A) \\ \text{or} \\ B(A) \end{matrix}$ where R(A) = range in TAPE8 corresponding to GPL=A.

(b3) $x(3) = GPL_2$; $y(3) = lin(GPL_2)$ where lin => linear interpolation.

(b4) $x(4) = B$; $y(4) = \begin{matrix} R(B) \\ \text{or} \\ B(B) \end{matrix}$

etc.

c) using the table of x,y values found above, use spline approximation to define the functions R(GPL) and B(GPL) for all values of GPL in the range given by GRIDF.

d) fill in the table by evaluation of the spline functions at the GPL label values.

Spline approximation is done using IMSL subroutine ICSFKU while evaluation is done by ICSEVU.

At present the spline approximation tables x,y are limited by array sizes to 60 entries.

e) write the range/bearing table onto TAPE9.

(10) Display the contents of TAPE9

Device CPY9 produces a well formatted printout of the contents of TAPE9 in table form.

In order to produce figures 2, 3, and 4, it is necessary to repeat all of the above steps for a different ionosphere but with the same target area. Figure 1 requires only 1 run through the above steps.

(11) Produce figure 1

Figure 1 is produced by device PREPLOT (PML352). The inputs to this device are a single range/bearing (R/B) table and some "instructions" for limiting and spacing the grid lines. First a few notes on the instructions. The user can specify the target zone grid by the two bearing limits b_l, b_h (in degrees) and two range limits r_l, r_h (in km). These limits do not need to agree with those given in step 1 but there is no reason to change them. Appropriate scaling factors and "nice" grid line spacings, del-b, del-r are determined then the target grid x,y values are found from

$x_{i,j} = 5 + r_i \cdot \sin(bb_j) \cdot s$

$y_{i,j} = c + r_i \cdot \cos(bb_j) \cdot s$

$bb_j \ = b_j - b_0$

b_0 = reference bearing from scaling subroutine.

c = plot position factor from scaling subroutine.

s = scale factor.

$r_i = r_l + (i-1) \cdot dr \qquad\qquad r_i \leq r_h$

$b_j = b_l + (j-1) \cdot db \qquad\qquad b_i \leq b_h$

dr, db are "good" range, beasring intervals determined by the scaling subroutine.

The constant bearing lines are determined by two points. Up to 40 points are used to define the constant range arcs which are actually drawn (at present) as straight lines between constant azimuth lines.

Although the user has control over target-region grid limits and no control over grid spacing, he does have control over the distorted grid spacing but essentially no control over the limits of this grid. The limits of this grid are determined by the GPL and az "labels" of the range/bearing table in TAPE9. There is an exception to this, however, if a user given limit is within the table limits, this user limit prevails.

The range/bearing table (r/b) with column labels azimuth (az) and row labels group path length (GPL) is considered to represent two smooth functions: r(az,GPL) and b(az,GPL). The "distorted grid" consists of arcs represented by $r(-,GPL_i)$, $b(-,GPL_i)$, the constant GPL arcs and $r(az_i,-)$, $b(az_i,-)$, the constant azimuth arcs. The constant GPL arc is found by finding the points $r(az_j,GPL_i)$, $b(az_j,GPL_i)$ for

$$az_j = az_1 + (j-1) \cdot \frac{daz}{2} \; ; \quad az_j \leq az_h$$

where

$az_1 = \max(az_1\text{-user},\ az_1\text{-table})$

$az_h = \min(az_h\text{-user},\ az_h\text{-table})$

daz = user supplied azimuth grid spacing

$j \leq 40$

$GPL_i = GPL_1 + (i-1)\ dGPL \quad ; \quad GPL_i \leq GPL_h$

$GPL_1 = \max(GPL_1\text{-user},\ GPL_1\text{-table})$

$GPL_h = \min(GPL_h\text{-user},\ GPL_h\text{-table})$

The point $r(az_j,GPL_i)$ is found by bi-cubic spline interpolation of the range/bearing table since, as a rule, az_j,GPL_i will not correspond to the table entry labels. This point is then transformed as above for the target grid and plotted.

The constant azimuth arcs are found in a similar fashion.

It should be noted that if, for example, az_1-user is less than az_1-table, the first azimuth grid arcs may have multiple labels indicating that it has been plotted several times. This happens because by definition, the points $[r(az_j, GPL_i), b(az_j,GPL_i)]$ are equal as long as az_j is less than az_1-table, i.e., no extrapolation out of the table is done.

PBFPLOT plots the target and distorted grids in different colors (assuming the multi-pen plotter is used) unless sense switch six is on, in which case a single pen is used.

(12) Produce figure 2

Device RBEPL2 (PML353) draws two distorted grids corresponding to the "standard" and "actual" ionospheres, on top of the target grid. The algorithm used and user supplied data is exactly the same as in step (11). For clarity, the 3-pen plotter is used with (normally) black ink for the target grid, green ink corresponds to TAPE91 and red ink to TAPE92.

(13) Produce figures 3 and 4

Figure 3 consists of the display of range/bearing error in the form of contours plots and figure 4 consists of "perspective view" plots of range error and bearing error. Thus, each of these figures consists of 2 parts.

The range error display and bearing error display are produced in separate cycles through device RBEDSP1 (PML 354) and DISPLAY (PML116). As for the distorted grid plots, the user may limit the azimuth-GPL domain of the plots through the use of az_l, az_h, GPL_l, GPL_h but as a rule this domain is defined by the intersection (in the set sense) of the domain of the two tables in TAPE91 and TAPE92. Here, daz and dGPL along with the table limits define the number of points or their location for function evaluation. Thus, the arrays which are displayed are:

range error:

$$r_1(az_j, GPL_i) - r_2(az_j, GPL_i)$$

bearing error:

$$b_1(az_j, GPL_i) - b_2(az_j, GPL_i)$$

$$az_j = az_l + (j-1) \cdot daz \quad ; az_j \leq az_h$$

$$GPL_i = GPL_l + (i-1) \cdot dGPL \quad ; GPL_i \leq GPL_h$$

$$j \leq 100 \quad ; \text{no limit on } i.$$

r_1 and b_1 are the range and bearings found from TAPE91 while r_2, b_2 are from TAPE92.

The values $r_{1,2}(-,-)$ and $b_{1,2}(-,-)$ are found by bi-cubic spline interplation of the tables as for the other plots.

The error function (actually array) to be displayed, either r_1-r_2 or b_1-b_2 is recorded on file TAPE3 along with some titling information. In addition, some scaling information, etc. is placed in file DSIN. These two files are then used as input to the general purpose display program, DISPLAY (PML116) which produces, in this case, contour plots and prespective view plots.

The contour intervals are found by merely dividing the function range into 10 equally spaced intervals which usually results in intervals which are awkward. For perspective plots, the range interval is rescaled so the plot will more or less fill the space allotted for it.

Finally the error functions (arrays) are temporarily stored on TAPE22 and printed in a nice fashion by a call to PRINT6 (PML320).

APPENDIX A - Example of Job Decks

Example of Job Decks to Produce Figures 1,2,3

(Deck 1 -- produce first "TAPE9")

```
BARTR,CM65000,T511.
ATTACH(JL,JURGLIBX3693818,ID=BANDES)
LIBRARY(JL)
BOXCOMT, $RUN FOR TROUGH1,ALL DEFAULTS$.
MKWALL.
SETTRC,CATOP,AZL=$22.5$,AZH=30,RNGL=1400,RNGH=1600,FRH=4,
   ELSTEP=5,ELH=20.
BOXCOMT, $CATALOG TROUGH1T9X3693818,ID=BANDES$.
```

(Deck 2 -- produce second "TAPE9")

```
BARTR,CM65000,T511.
ATTACH(JL,JURGLIBX3693818,ID=BANDES)
LIBRARY(JL)
BOXCOMT, $RUN FOR TROUGH1A,F2MX=3.71$.
MKWALL.
SETTRC,CATOP,AZL=$22.5$,AZH=30,RNGL=1400,RNGH=1600,FRH=4,
   ELSTEP=5,ELH=20,MODOU=TROUGH1A,F2MX=$3.71$.
BOXCOMT, $CATALOG TROUGH1AT9X3693818,ID=BANDES$.
```

(Deck 3 -- produce figures)

```
BARTR,CM65000,T511.
ATTACH(JL,JURGLIBX3693818,ID=BANDES)
ATTACH(IM,IMSLLIBX3693818,ID=BANDES)
ATTACH(UT,UTILLIBX3693818,ID=BANDES)
LIBRARY(JL)
FIGURES,REFERENCE=TROUGH1,ACTUAL=TROUGH1A,LIB=$JL/IM/UT$.
```

```
.PROC,JBPCOM,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
MODIN=TROUGH1,MODOU=TROUGH1,EXT=3693818,ID=BANDES,
PARTIC=1.
.*
.* UNIFORM PARAMETERS FOR JURGEN BUCHAU PROCEDURES --
.*
.*  CATOP -- CATALOG OUTPUT FILE?  OMITTED - NO, INCLUDED - YES.
.*  UNLDF -- UNLOAD  OUTPUT FILE?  OMITTED - SAVE IT, INCLUDED - UNLOAD.
.*  GETIP -- ATTACH  INPUT  FILE?  OMITTED - NO, INCLUDED - YES.
.*
.*  MODIN -- PF GIVEN NAME FOR INPUT FILE (SEE MODOU FOR USE)
.*  MODOU -- PF GIVEN NAME FOR OUTPUT FILE (TO BE CATENATED WITH
.*              PARTICULAR NAME FOR FILE, I.E. MODOU_TIX_EXT.
.*  EXT   -- PHONE EXTENSION, DEFAULTS TO 3693818
.*  ID    -- OWNER-ID FOR CATALOG, DEFAULTS TO BANDES.
.*              NOTE EXT AND ID ARE SAME FOR INPUT, OUTPUT FILES.
.*  INLFN, OUTLFN, TILFN -- FILE NAMES FOR INPUT, OUTPUT, TAPE I.
.PROC,MKWALL,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
MODIN=TROUGH1,MODOU=$06UT$,EXT=3693818,ID=BANDES,
INLFN=#DATA,OUTLFN=OUTPUT,T6LFN=TAPE6,
L295=$51.5$,L300=$52.5$,L305=$53.7$,L310=$55.4$,L315=$57.2$,
L320=$59.6$,L325=$61.9$,L330=$64.3$,L335=$66.3$,L340=$68.2$.
IFE,$CATOP$=$YES$,TST1.
REQUEST(T6LFN,*PF)
ENDIF,TST1.
ATTACH(ML,BASICLIBX3693818,#ID=WONG,MR=1)
LDSET(PRESET=ZERO,LIB=ML)
WALL(INLFN,OUTLFN,,T6LFN)
IFE,$CATOP$=$YES$,TST2.
CATALOG(T6LFN,MODOU_T6X_EXT,#ID=ID)
ENDIF,TST2.
IFE,$UNLDF$=$YES$,TST3.
UNLOAD,T6LFN.
ENDIF,TST3.
REWIND,T6LFN.
EXIT,U.
UNLOAD(ML)
.DATA
MODOU
L295        295.
L300        300.
L305        305.
L310        310.
L315        315.
L320        320.
L325        325.
L330        330.
```

```
L335        335.
L340        340.
.PROC,JBRAYS,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,SAVE6=NO/YES,
MODIN=$06UT$,MODOU=TROUGH1,EXT=3693818,ID=BANDES,
F2MX=$3.81$,F2MN=$1.97$,PMAX=$0.05235987$,
WN1=$199$,WN2=$199$,WN3=$199$,WN4=$199$,WN5=$199$,
WV1=$0.$,WV2=$0.$,WV3=$0.$,WV4=$0.$,WV5=$0.$,
OUTLFN=OUTPUT,INLFN=#DATA,T3LFN=TAPE3,T6LFN=TAPE6,T7LFN=TAPE7,
T8LFN=TAPE8,PL=30000.
.*
.* REVISION -- FEBRUARY 28, 1979
.* AUTHOR   --  BANDES D
.* PURPOSE --  RUN RAY-TRACE FOR JURGEN.  ASSUMES JURGLIB IS GLOBAL
.*                LIBRARY WITH LFN JL.
.*
.* PARAMETERS
.*
.*  CATOP        CATALOG TAPE7? OMITTED - NO, INCLUDED - YES.
.*  ID          OWNER-ID FOR TAPE7 IF CATALOGED
.*  MODOU        IDENTIFIER FOR RAY-TRACE RUN, PART OF TAPE7 PFN.
.*  F2MX        VALUE FOR W(101) CONTROLS BCHAP -- F2 MAXIMUM
.*  F2MN                 W(102)                -- F2 MINIMUM
.*  PMAX                 W(103) **RADIANS**    -- TROUGH WIDTH
.*  WN1-WN5     SPARE W-ARRAY SUBSCRIPTS.  MUST BE 3 DIGITS, E.G., 004
.*  WV1-WV5     SPARE W-ARRAY VALUES, W(WNI) = WVI.
.*  OUTLFN      LFN FOR OUTPUT
.*  INLFN       LFN FOR INPUT
.*  T3LFN..T8LFN  LFN FOR TAPE3, .. TAPE8
.*  PL          PRINT LINE LIMIT
.*
IFE,$CATOP$=$YES$,TST1.
REQUEST(T7LFN,*PF)
ENDIF,TST1.
IFE,$GETIP$=$YES$,TST2.
ATTACH(T6LFN,MODIN_T6X_EXT,#ID=ID,MR=1)
ENDIF,TST2.
ATTACH(ML,BASICLIBX3693818,#ID=WONG,MR=1)
LDSET(PRESET=ZERO,LIB=JL/ML,SUBST=TRCRPRT-TRCRPXL)
LIBLOAD(JL,BCHAP,TRCRPXL)
NITIAL(INLFN,OUTLFN,,,T3LFN,T6LFN,T7LFN,T8LFN,#PL=PL)
EXIT,U.
UNLOAD,ML.
IFE,$SAVE6$=$NO$,UL6TST.
UNLOAD,T6LFN.
ENDIF,UL6TST.
IFE,$CATOP$=$YES$,TST3.
CATALOG(T7LFN,MODOU_T7X_EXT,#ID=ID)
ENDIF,TST3.
IFE,$UNLDF$=$YES$,TST4.
```

```
UNLOAD,T7LFN.
ENDIF,TST4.
.DATA
MODOU   FROM PROCEDURE JBRAYS
  4  56.2        1
  5   2.4        1
  7   2.
  7   5.
  8   5.
  9   0.
 11  25.         1
 12  45.         1
 13  10.         1
 15   0.         1
 16  10.         1
 17  10.         1
 90  5000.
 99   1.
 71  10.
 73   2.
101  F2MX
102  F2MN
103  PMAX
WN1  WV1
WN2  WV2
WN3  WV3
WN4  WV4
WN5  WV5
  0
.PROC,MKTAP8,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
MODIN=TROUGH1,MODOU=TROUGH1,EXT=3693818,ID=BANDES,
INLFN=INPUT,OUTLFN=OUTPUT,REPORT=NO/YES.
IFE,$GETIP$=$YES$,TST1.
ATTACH(TAPE7,MODIN_T7X_EXT,#ID=ID,MR=1)
ENDIF,TST1.
IFE,$CATOP$=$YES$,TST2.
REQUEST(TAPE8,*PF)
ENDIF,TST2.
REWIND,TAPE7.
ATTACH(ML,BASICLIBX3693818,#ID=WONG,MR=1)
ATTACH(INF,INFOLIBX3693818,#ID=BANDES,MR=1)
ATTACH(UL,UTILLIBX3693818,#ID=BANDES,MR=1)
LDSET(PRESET=ZERO,LIB=ML/UL/INF)
DRVT7R(INLFN,OUTLFN)MODEL=MODOU.
UNLOAD,TAPE7.
IFE,$CATOP$=$YES$,TST3.
CATALOG(TAPE8,MODOU_T8X_EXT,#ID=ID)
ENDIF,TST3.
REWIND,TAPE8.
```

```
IFE,$REPORT$=$YES$,TST4.
CPY8(TAPE8,OUTLFN)
ENDIF,TST4.
IFE,$UNLDF$=$YES$,TST5.
UNLOAD,TAPE8.
ENDIF,TST5.
UNLOAD,ML,UL,INF.
.PROC,MKTAP9,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
MODIN=TROUGH1,MODOU=TROUGH1,EXT=3693818,ID=BANDES,
REPORT=NO/YES,MANGRID=NO/YES,OUTLFN=OUTPUT,T8LFN=TAPE8,
GRLFN=GRIDF,T9LFN=TAPE9.
.*
.* MAKE TAPE9 FROM TAPE8
.*
.* SPECIAL PARAMETERS --
.*  REPORT  INCLUDED, PUT TAPE9 THROUGH CPY9
.*  MANGRID OMITTED, LET PROGRAM T8GRID SELECT OUTPUT AZ, GPL GRID
.*          INCLUDED, MANUALLY-GENERATED GRID IS SUPPLIED ON FILE
.*            GRLFN (IT MUST BE POSITIONED CORRECTLY BEFORE
.*            THIS PROCEDURE IS CALLED)
.*  GRLFN   FILE WITH GRID (NAMELIST DATA)
.*
ATTACH(IML,IMSLLIBX3693818,#ID=WONG,MR=1)
IFE,$GETIP$=$YES$,TST1.
ATTACH(T8LFN,MODIN_T8X_EXT,#ID=ID,MR=1)
ENDIF,TST1.
IFE,$MANGRID$=$NO$,MGTST.
T8GRID(T8LFN,GRLFN,OUTLFN)
REWIND,GRLFN.
ENDIF,MGTST.
IFE,$CATOP$=$YES$,TST2.
REQUEST(T9LFN,*PF)
ENDIF,TST2.
LDSET(PRESET=ZERO,LIB=IML)
DEVØ(GRLFN,OUTLFN,T8LFN,T9LFN)
EXIT,U.
IFE,$CATOP$=$YES$,TST3.
CATALOG(T9LFN,MODOU_T9X_EXT,#ID=ID)
ENDIF,TST3.
IFE,$REPORT$=$YES$,TST4.
CPY9(T9LFN,OUTLFN)
ENDIF,TST4.
EXIT,U.
IFE,$UNLDF$=$YES$,TST5.
UNLOAD,T9LFN.
ENDIF,TST5.
UNLOAD,TAPE8.
RETURN,IML.
.PROC,SETTRC,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
```

```
MODIN=$Ø6UT$,MODOU=TROUGH1,EXT=3693818,ID=BANDES,
INLFN=#DATA,OUTLFN=OUTPUT,T6LFN=TAPE6,
F2MX=$3.81$,F2MN=$1.97$,PMAX=$3.Ø$,
FRL=$4.Ø$,FRH=$9.Ø$,FRSTEP=$1.Ø$,ELL=$Ø.Ø$,ELH=$3Ø.Ø$,ELSTEP=$4.Ø$,
AZL=$24.Ø$,AZH=$32.Ø$,HTL=$Ø.Ø$,HTH=$1Ø.Ø$,RNGL=$9ØØ.Ø$,RNGH=$115Ø.Ø$.
.*
.* REVISION -- MARCH 2, 1979
.* AUTHOR   -- BANDES D
.* PURPOSE  -- SET UP AND RUN BIG RAY-TRACE FOR JURGEN
.* ONE OF THE BIGGER PROCEDURES FOR J. BUCHAU
.* ATTEMPTS TO TRACE RAYS DENSELY IN A TARGET AREA
.* SPECIAL PARAMETERS --
.*  AZL, AZH -- LOW AND HIGH AZIMUTH LIMITS OF TARGET AREA
.*  HTL, HTH --       "        HEIGHT         "
.*  RNGL, RNGH --     "        RANGE          "
.*  FRL, FRH --       "        FREQUENCY LIMITS FOR TRIAL RAY-TRACE
.*  ELL, ELH          "        ELEVATION          "
.*  FRSTEP, ELSTEP -- FREQ, ELEVATION STEPS
.*  F2MX, F2MN, PMAX -- PARAMS FOR BCHAP, SEE JBRAYS OR PML 151
.*                      BUT PMAX IN DEGREES
UNLOAD,TARGET.
COPYCR,INLFN,TARGET.
REWIND,TARGET.
TTOWP,#INLFN=TARGET,#OUTLFN=WTAPE.
REWIND,WTAPE.
JBRAYS,#GETIP=GETIP,#MODIN=MODIN,#INLFN=WTAPE,SAVE6.
REWIND,TARGET,TAPE7.
UNLOAD,TAPE8.
MKTAP8,#INLFN=TARGET,#MODOU=MODOU,REPORT.
UNLOAD,TAPE7.
REWIND,TAPE8,TARGET.
UNLOAD,WTAPE.
T8TOWP,#INLFN=TARGET,#OUTLFN=WTAPE.
REWIND,WTAPE,TAPE6.
JBRAYS,#INLFN=WTAPE,SAVE6.
REWIND,TARGET,TAPE7.
UNLOAD,TAPE8.
MKTAP8,#INLFN=TARGET,#CATOP=CATOP,#MODOU=MODOU,REPORT.
REWIND,TAPE8,TARGET.
UNLOAD,TAPE9.
MKTAP9,#CATOP=CATOP,#MODOU=MODOU.
.DATA
 $TARGET
 #AZL = AZL,
 #AZH = AZH,
 #HTL = HTL,
 #HTH = HTH,
 #RNGL = RNGL,
 #RNGH = RNGH,
```

```
 $
 $TROUGH
 #F2MX = F2MX,
 #F2MN = F2MN,
 #PMAX = PMAX,
 $
 $RAYSPX
 #FRL = FRL,
 #FRH = FRH,
 #FRSTEP = FRSTEP,
 #ELL = ELL,
 #ELH = ELH,
 #ELSTEP = ELSTEP,
 $
.PROC,TTOWP,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
MODIN=ZONE1,MODOU=ZONE1,EXT=3693818,ID=BANDES,
INLFN=INPUT,OUTLFN=WTAPE.
IFE,$CATOP$=$YES$,TST1.
REQUEST(OUTLFN,*PF)
ENDIF,TST1.
TTOW(INLFN,OUTLFN)
IFE,$CATOP$=$YES$,TST2.
CATALOG(OUTLFN,MODOU_WTPX_EXT,#ID=ID)
ENDIF,TST2.
.PROC,T8TOWP,CATOP=NO/YES,UNLDF=NO/YES,GETIP=NO/YES,
MODIN=ZONE1,MODOU=ZONE1,EXT=3693818,ID=BANDES,
INLFN=INPUT,OUTLFN=WTAPE,T8LFN=TAPE8.
IFE,$CATOP$=$YES$,TST1.
REQUEST(OUTLFN,*PF)
ENDIF,TST1.
T8TOW(INLFN,OUTLFN,T8LFN)
IFE,$CATOP$=$YES$,TST2.
CATALOG(OUTLFN,MODOU_WTFX_EXT,#ID=ID)
ENDIF,TST2.
```

```
.PROC,FIGURES,BRL=20,BRH=30,RNGL=1400,RNGH=1600,AZL=0,AZH=360,
AZSTEP=$.5$,GPLL=0,GPLH=10000,GPLSTEP=20,AZLC=0,AZHC=360,AZSTEPC=$.1$,
GPLLC=0,GPLHC=10000,GPLSTEPC=1,VIEW=$-135$,STANDARD=TROUGH1,
ACTUAL=TROUGH1A,EXT=3693818,ID=BANDES,LIB=$JU/IM/UT$,SWITCH6=OFF/ON,
REDINK=OFF/ON,OFFLINE=OFF/ON.
.*
.* REVISION -- FEBRUARY 29,1980
.* AUTHOR   -- BARRETT,TB
.* PURPOSE  -- PLOT FIGURES 1,2,3,4 FOR OTH RADAR ERROR DISPLAY.
.*
.* PARAMETERS
.*
.*    BRL     (20)     LOW BEARING LIMIT FOR TARGET ZONE (DEG)
.*    BRH     (30)     HIGH BEARING LIMIT FOR TARGET ZONE
.*    RNGL    (1400)   LOW RANGE LIMIT FOR TARGET ZONE (KM)
.*    RNGH    (1600)   HIGH RANGE LIMIT FOR TARGET ZONE
.*    AZL     (0)      LOW AZIMUTH LIMIT FOR DISTORTED GRID (DEG)
.*    AZH     (360)    HIGH AZIMUTH LIMIT FOR DISTORTED GRID
.*    AZSTEP  (.5)     AZIMUTH STEP FOR DISTORTED GRID
.*    GPLL    (10)     LOW GPL LIMIT FOR DISTORTED GRID (KM)
.*    GPLH    (10000)  HIGH GPL LIMIT FOR DISTORTED GRID
.*    GPLSTEP (20)     GPL STEP FOR DISTORTED GRID
.*    AZLC    (0)      LOW AZIMUTH LIMIT FOR ERROR PLOT (DEG)
.*    AZHC    (360)    HIGH AZIMUTH LIMIT FOR ERROR PLOT
.*    AZSTEPC(.1)      AZIMUTH INTERVAL FOR ERROR PLOT
.*    GPLC    (0)      LOW GPL LIMIT FOR ERROR PLOT
.*    GPLHC   (10000)  HIGH GPL LIMIT FOR ERROR PLOT
.*    GPLSTEPC (1)     GPL INTERVAL FOR ERROR PLOT
.*    VIEW    (-135)   VIEW ANGLE FOR PERSPECTIVE PLOT
.*    STANDARD (TROUGH1) LABEL FOR THE STANDARD IONOSPHERE.
.*    ACTUAL   (TROUGH1A) LABEL FOR THE ACTUAL IONOSPHERE
.*    EXT     (3693818) SEE BELOW
.*    ID      (BANDES) SEE BELOW
.*                     THE 2 "TAPE9" TABLES ARE ATTACHED AS
.*                     (TAPE91,STANDARD_T9X_EXT,#ID=ID)    AND
.*                     (TAPE92,ACTUAL_T9X_EXT,#ID=ID)
.*    LIB     (JU/IM/UT) THESE ARE THE LFN'S OF THE LIBRARIES
.*                        CONTAINING ALL THE MODULES EXCEPT AFGL
.*                        AND SYSTEM MODULES.
.*    SWITCH6 (OFF/ON)  IF SWITCH6 IS SPECIFIED, FIG. 1 IS DONE
.*                      WITH ONLY ONE PEN
.*    REDINK  (OFF/ON)  IF SPECIFIED PLOTS ARE DISPOSED TO THE
.*                      REDINK QUEUE
.*    OFFLINE (OFF/ON)  IF SPECIFIED, THE OFFLINE PLOTTER IS USED.
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.**********************************************************************
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ATTACH(TAPE91,STANDARD_T9X_EXT,#ID=ID)
EXIT(U)
SET,R1=FILE(TAPE91,PF).
ATTACH(TAPE92,ACTUAL_T9X_EXT,#ID=ID)
EXIT(U)
SET,R2=FILE(TAPE92,PF).
IFE,(R1=0).AND.(R2=0),LAB1.
REVERT.
ENDIF,LAB1.
IFE,$SWITCH6$=$ON$,LAB0.
SWITCH(6)
ENDIF,LAB0.
IFE,$OFFLINE$=$ON$,LAB2.
REQUEST(TAPE39,*Q)
ATTACH(PEN,OFFLINEPEN)
IFE,$REDINK$=$ON$,LAB3.
DISPOSE(TAPE39,*LR)
ELSE,LAB3.
DISPOSE(TAPE39,*LL)
ENDIF,LAB3.
ELSE,LAB2.
REQUEST(PLOT,*Q)
ATTACH(PEN,ONLINEPEN)
IFE,$REDINK$=$ON$,LAB4.
DISPOSE(PLOT,*PL)
ELSE,LAB4.
DISPOSE(PLOT,*OL)
ENDIF,LAB4.
ENDIF,LAB2.
LIBRARY(PEN)
IFE,R1=1,LAB5.
LDSET(PRESET=0,#LIB=LIB)
RBEPLOT(INPUTF,,TAPE91)
REWIND(TAPE91,INPUTF)
ENDIF,LAB5.
IFE,R2=1,LAB6.
LDSET(PRESET=0,#LIB=LIB)
RBEPLOT(INPUTF,,TAPE92)
REWIND(TAPE92,INPUTF)
ENDIF,LAB6.
IFE,(R1=1).AND.(R2=1),LAB7.
LDSET(PRESET=0,#LIB=LIB)
RBEPL2(INPUTF,,TAPE91,TAPE92)
REWIND(TAPE91,TAPE92)
LDSET(PRESET=0,#LIB=LIB)
RBEDSP1(INPUTG)
REWIND(TAPE3,DSIN)
DISPLAY(DSIN)
REWIND(TAPE91,TAPE92,TAPE3,DSIN)
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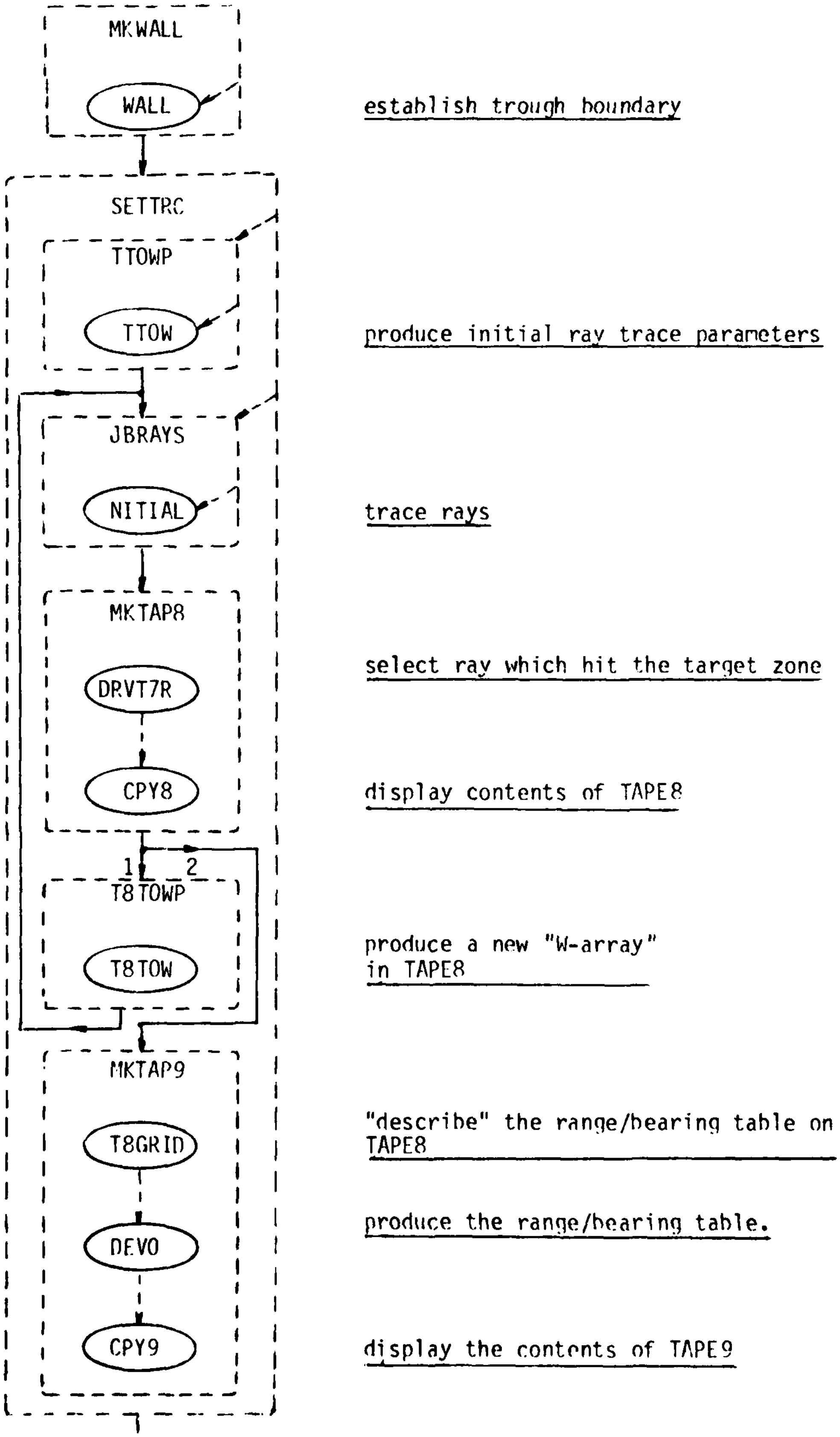
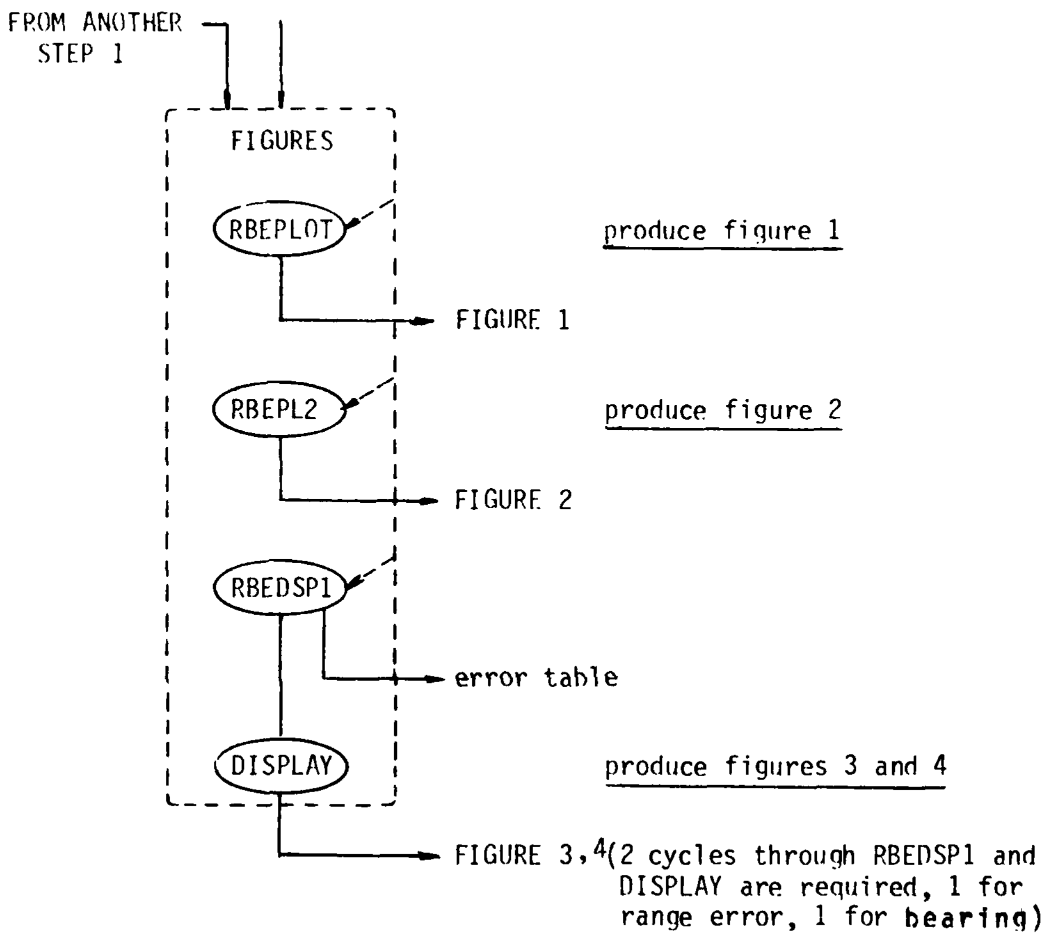
```
LDSET(PRESET=0,#LIB=LIB)
RBEDSP1(INPUTH)
REWIND(TAPE3,DSIN)
DISPLAY(DSIN)
REWIND(TAPE6)
COPY(TAPE6)
EXIT(U)
ENDIF,LAB7.
RETURN(TAPE91,TAPE92,PEN,TAPE39,PLOT,TAPE6,TAPE5,TAPE3)
RETURN(INPUTF,INPUTG,INPUTH,DSIN)
.DATA INPUTF
 $TARGET
 #AZL=BRL,
 #AZH=BRH,
 #RNGL=RNGL,
 #RNGH=RNGH,
 $END
 $GRID
 #AZL=AZL,
 #AZH=AZH,
 #AZSTEP=AZSTEP,
 #GPLL=GPLL,
 #GPLH=GPLH,
 #GPLSTEP=GPLSTEP,
 $END
.DATA INPUTG
RANGE     VIEW
 $GRID
 #AZL=AZLC,
 #AZH=AZHC,
 #AZSTEP=AZSTEPC,
 #GPLL=GPLLC,
 #GPLH=GPLHC,
 #GPLSTEP=GPLSTEPC,
 $END
.DATA INPUTH
BEARING   VIEW
 $GRID
 #AZL=AZLC,
 #AZH=AZHC,
 #AZSTEP=AZSTEPC,
 #GPLL=GPLLC,
 #GPLH=GPLHC,
 #GPLSTEP=GPLSTEPC,
 $END
```

Procedure/Device Flow Diagram

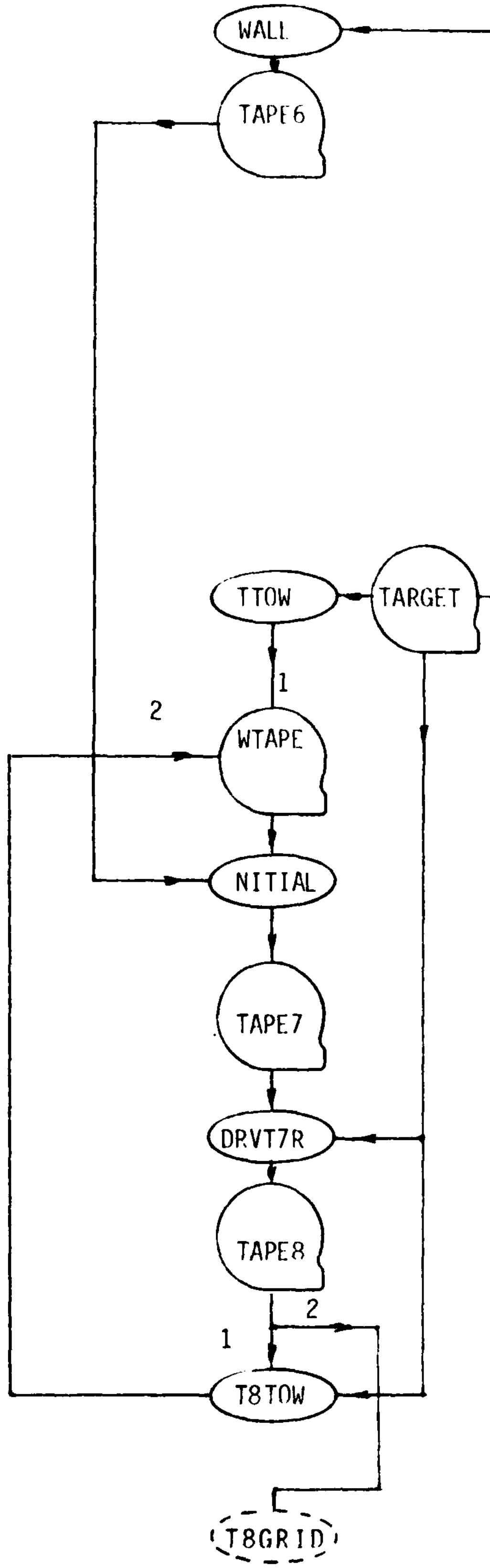
STEP 1 -- Produce the display data for one ionosphere
(This step is repeated for figures 2, 3, 4.)



STEP 2 -- Produce figures 1, 2, 3,4



Data Flow Diagram



MKWALL
Specify trough boundary by geographic latitude for geographic longitudes [295.,340.(5.)].
L295(51.5),L300(52.5),L305(53.7),
L210(55.4),L315(57.2),L320(59.6),
L325(61.9),L330(64.3),L335(66.3),
L340(68.2),MODOU(O6UT)* 1-word title to identify trough boundary.

SETTRC
(1) target zone description
AZL(24.0),AZH(37.0) low/high azimuth limits (deg dipole geomagnetic)
HTL(0.0),HTH(10.0) low/high height limits (km)
RNGL(900.0),RNGH(1150.0) low/high range limits (km)
(2) trough parameters
F2MX(3.81) max plasma frequency (MHz) at "top" of trough
F2MN(1.97) max plasma frequency (MHz) at "bottom" of trough
PMAX(3.0) trough width (if PMAX ≤ .2, width is in radians; otherwise, degrees)
(3) describe rays (initial description)
FRL(4.0) low frequency limit (MHz)
FRH(9.0) high frequency limit
FRSTEP(1.0) frequency step
ELL(0.0) low elev. angle limit (deg)
ELH(30.0) high elev. angle limit
ELSTEP(4.0) elevation step
(4) MODOU (TROUGH1)

* default data values are shown in parentheses.

Data Flow Diagram (continued)